A Novel Compensating Technique for Power Factor Improvement in Power Electronic Systems

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Abstract **–Power electronics systems are non-linear systems, which consume more reactive power and also the loads they feed are mostly inductive loads which leads to a poor power factor. Various compensation techniques are available to bring the power factor nearer to unity. In this paper, a novel compensator is proposed, where in-phase and quadrature components of the supply current are vector-controlled. Implementation of this compensator in a power electronic system operating with a very poor power factor (and hence high THD), shows that the system then draws a leading current. A conventional power electronic system, A conventional power electronic system with one of the traditional static VAR compensators and the conventional power electronic system incorporated with the proposed compensator are simulated and the simulation results are obtained. It is shown that the proposed method offers only 0.7% THD, which also implies that the power factor is improved.**

Keywords: **Total Harmonic Distortion, Vector Control, Compensator, Switching, Power Electronic Converters**

I.INTRODUCTION

The Power Electronics converters have been increasingly employed in recent years owing to their advanced features including sinusoidal input current at unity power factor. Power electronic devices that have rapid and frequent load variations have become abundant today due to their many process control Supply side is developed. The in-phase component of the supply current I_p is kept constant, whereas the quadrature component of the supply current I_Q is controlled from the output of the speed loop. The vector control is formulated in d-q axis coordinated frame, the method requires on-line coordinate transformations that convert the line current in three related and energy saving benefits. These features are not necessarily achieved under the operating conditions of unbalanced input supply and input impedances. Such a generalized unbalanced operating condition is quite common in power systems, as the electrical energy is generated, transmitted in the form of alternating current. To meet this requirement, it is customary to add a power factor correction circuit. The low power factor is due to the power loads that are inductive which take lagging currents and hence lagging power factor [4]. To improve the power factor, device supplying reactive power are connected in parallel to the system at desired location. The capacitor draws a leading current and neutralizes the lagging reactive component of load current. This raises the power factor of the load. However they do not regulate the instantaneous power explicitly. So that it is not suitable for implementation. Various methods of VAR compensation are synchronous condensers, mechanically switched capacitors etc.,[7,8].With the advent of power electronic switches, TSC-Thyristor switched capacitor, has been used to absorb or inject reactive power[5,6].

This paper proposes a new control scheme in which a vector control method on the phase rotating frame to two phase synchronously rotating frame representation and vice versa [2], [3]. The d-q components of the input voltages and currents are employed to accurately describe the behavior of the converter. The proposed vector control scheme [1] allows the system to draw a leading current. Because the current is leading, THD is drastically reduced.

Because of the growing concern about harmonic pollution there is a need to reduce the harmonic contents of the AC line current of power supplies. Harmonics may disrupt normal operation of devices. Therefore rapid reactive power changes demand timely reactive VAR compensation. Even with that, the THD is not up to the specified standards.

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II. CONVENTIONAL METHOD

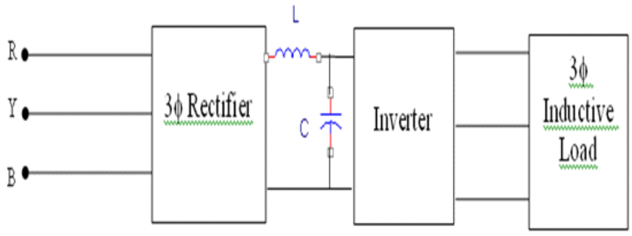

Fig 1 A Power Electronics System with No Compensation Technique

A power electronics system with no compensator is shown in fig 1

The three phase supply is fed to the three phase rectifier which further, through a DC link feeds a three phase inverter. The load used is inductive or non-linear which will draw lagging current and hence poor power factor results.

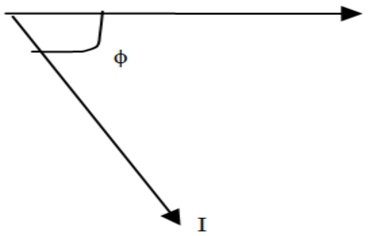

Fig 2 Phasor diagram of the System without Compensator

The phasor representation of this system is shown in fig 2.It can be noted that the power factor is very poor.

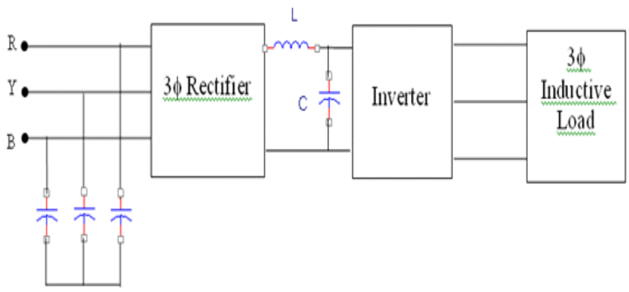

Fig 3 Power Electronics System with Static VAR Compensation

A power electronics system with compensator at the supply side is shown in fig 3. The three phase supply is fed to the three phase rectifier which further, through a DC link feeds a three phase inverter. The load used is inductive or non-linear which will draw lagging current and hence poor power factor results. However because of the introduction of the compensator, the leading current drawn by the same also gets vectorially added with the load current and so the resultant current gets shifted towards the voltage phasor, i.e., the power factor is improved than the conventional system.

The phasor representation of this system is shown in fig 4.It can be noted that the power factor is improved than the conventional system.

Since the power factor is improved the THD, i.e., the total harmonic distortion is reduced as these two have the inverse relationship. Also the drawback in this way of compensation is that the capacitance value can be changed in steps only. Though a dynamic Var compensator be used for PFC, it will have rotational losses, which will add up with the total losses

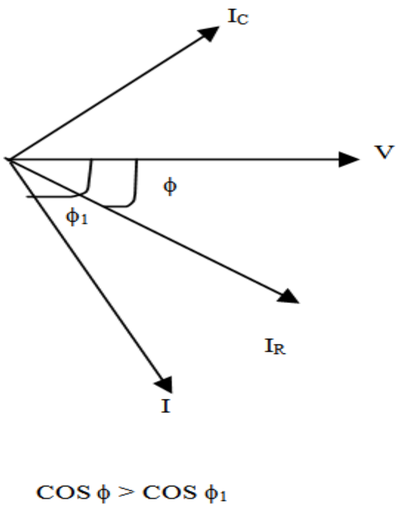

Fig 4 Phasor diagram of the System with Compensator

III.THE PROPOSED METHOD

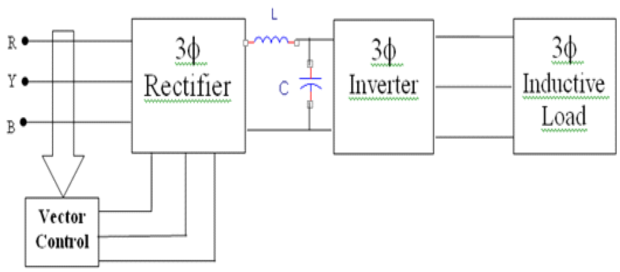

Fig 5 Power Electronics System with the proposed Compensator.

The block diagram of a power electronics system is shown in the figure 5.As seen vector control is implemented on the supply side, i.e., the three phase currents are converted to two phase currents using Park's transformation and the control is implemented on to the rectifier control i.e., the switching of the rectifier. The rectifier then feeds the three phase inverter which further feeds the three phase inductive load. The phasor diagramsfor such a circuit are discussed in what follows.The current components I_p and I_q (I_p-the active component and I_q-the reactive component) are regulated by vector control. The orthogonal spatial orientation between I_p an I_q is achieved by unit vectors and

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these unit vectors are generated from line voltage vector. Because VC is used, the appropriate 3phase-2phase and 2phase-3phase transformation are done at appropriate places.The transformation equations from 3 phase synchronously rotating frame to 2 phase synchronously rotating frame and vice versa are given below.The 3phase voltages and 3 phase currents are sensed and individually (that is voltage and current) are transformed to 2 phase stationary frame voltages. This is obvious from the phasor diagram as shown in fig S6.

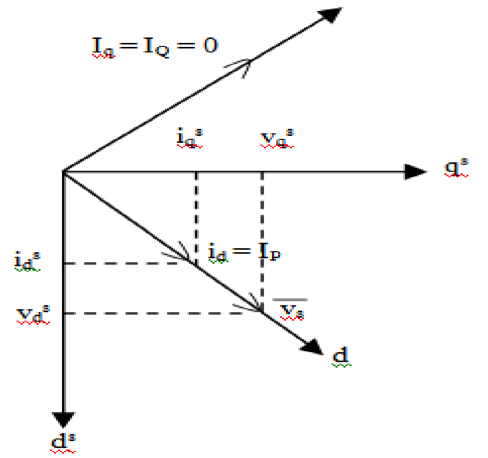

Fig 6 Phasor diagram of the proposed Scheme during implementation

$$\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = (2/3)^{0.5} \begin{bmatrix} \cos\theta & \sin\theta & 0.707 \\ \cos(\theta - 2\pi/3) & \sin(\theta - 2\pi/3) & 0.707 \\ \cos(\theta - 4\pi/3) & \sin(\theta - 4\pi/3) & 0.707 \end{bmatrix} \begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix}$$

$$\begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} = (2/3)^{0.5} \begin{bmatrix} \cos\theta & \cos(\theta - 2\pi/3) & \cos(\theta - 4\pi/3) \\ \sin\theta & \sin(\theta - 2\pi/3) & \sin(\theta - 4\pi/3) \\ 0.707 & 0.707 & 0.707 \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

$$\begin{bmatrix} i_d^s \\ i_q^s \\ i_0^s \end{bmatrix} = (2/3)^{0.5} \begin{bmatrix} \cos\theta & \cos(\theta - 2\pi/3) & \cos(\theta - 4\pi/3) \\ -\sin\theta & -\sin(\theta - 2\pi/3) & -\sin(\theta - 4\pi/3) \\ 0.707 & 0.707 & 0.707 \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

From this,

$$V_d^s = V_s \cos\theta \qquad (1)$$

$$V_q^s = V_s \sin \qquad (2)$$

$$\cos\theta = V_d^s / V_s \qquad (3)$$

$$\sin\theta = V_q^s / V_s \qquad (4)$$

Also in the 2 phase synchronously rotating frame

$$i_d = I_P \qquad (5)$$

$$i_q = I_Q = 0 \qquad (6)$$

$$i_d^s = I_P \cos\theta \qquad (7)$$

$$i_q^s = I_P \sin\theta \qquad (8)$$

Because of the particular switching, as apparent from the fig, the thyristors in the rectifier unit will conduct only for certain period at regular intervals.

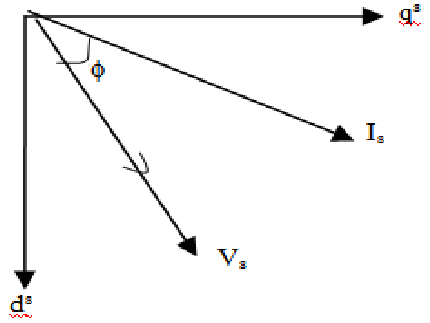

Fig 7 Resultant Phasor diagram of the Proposed scheme.

This leads to reduced conduction losses and hence reduced heat losses. This adds to the improved efficiency of the system. The current component reactive power i.e. i_q^*, where, . i_q^* is the command value is set to zero and so, whatever be the reactive current component of the system (I_Q), the closed loop control will always try to make the total reactive current to be zero. Because an additional emf is also injected into the circuit and as a whole effect of vector control and this emf, the power factor is improved much, i.e. it becomes a leading power factor or in other words, the current phasor leads the voltage phasor as shown in fig 7.

IV. SIMULINK CIRCUITS

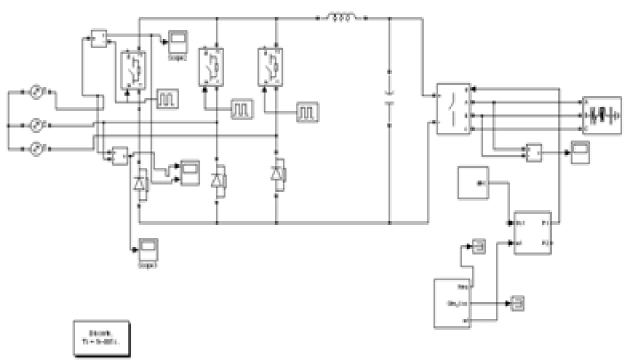

Fig 8 Conventional system with no compensator

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A conventional power system is shown in fig. in which a three phase rectifier is fed by a three phase supply. Through a DC link the output of the rectifier is fed to a three phase inverter. A universal bridge is used in the inverter mode. A separate space vector generator circuit generates the space vector modulated signals which is fed as the input to the gates if the universal bridge. A highly inductive load is connected to the output of the inverter.For this typical system the input voltage and current waveforms are obtained and alsotheTHDis obtained which arediscussedinthelatersections.

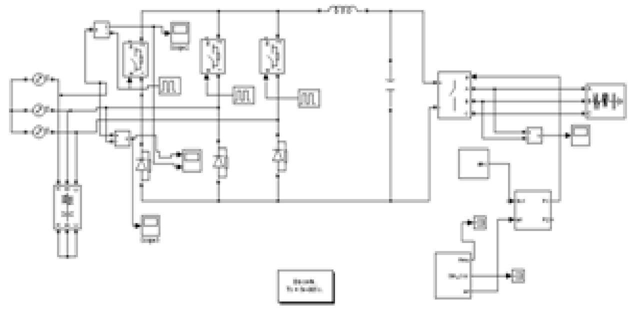

Fig 9 Conventional system with static VAr Compensator

A power system with a static VAr compensator at the supply side is shown in fig. in which a three phase rectifier is fed by a three phase supply. Through a DC link the output of the rectifier is fed to a three phase inverter. A universal bridge is used in the inverter mode. A separate space vector generator circuit generates the space vector modulated signals which is fed as the input to the gates if the universal bridge. A highly inductive load is connected to the output of the inverter.

For this system the input voltage and current waveforms are obtained and also the THD is obtained which are discussed in the later sections.

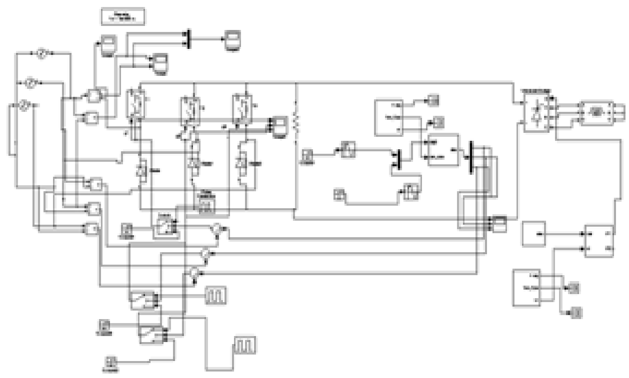

Fig 10 Conventional System with proposed Compensator

The proposed novel compensator for a power system is shown in fig 10. The three phase supply is fed to a semi controlled converter and it is chosen because then the circuit will have an input current which is rich in harmonics, than when compared to a fully controlled rectifier. Through a DC link this semi converter feeds a three phase inverter (again an universal bridge is used).

The input voltage and current in three phase synchronously rotating frame are then converted to voltage and current in two phase synchronously rotating frame. These voltages are then fed to a comparator where the other input to the comparator is the supply voltage itself.

The error signal then decides the conduction of the switches in the semi converter. It is this feedback which decides the triggering of the appropriate switches. Of course the phase delay is the same as done in the traditional circuit.

The inverter is given with SVM pulses for its gates. The load connected to the inverter is a highly inductive load which is one of the causes for poor power factor.

IV. TABULATION

S.No	Circuit	%THD values
1)	Conventional system with no compensator	95.85
2)	Conventional system with static VAR compensator	93.60
3)	Conventional system with the proposed novel compensator	0.7

Table 1 Percentage THD obtained with different Simulink circuits

V. WAVEFORMS AND OBSERVATIONS

The waveforms of the above simulink circuits are shown in the following figures. The values of THD obtained with the above circuits are tabulated in table 1.

The input voltage and current waveforms of the conventional system is shown in fig11 .It can be observed that the input current is non-sinusoidal and is rich in harmonics whose THD value is 95.85%.Also the THD obtained with this system is shown in fig 12.

The input voltage and current waveforms of the conventional system with static Var compensator is shown in fig 13.Even here the input current is non-sinusoidal and is rich in harmonics and its THD value is 93.60%, shown in fig 14.

In the figure15, is shown the input voltage and input current waveforms of the conventional system incorporated with the proposed compensator. The THD is also shown in fig. 16 where the THD value is only 0.7% and this is because the input current is leading with respect to the input voltage.

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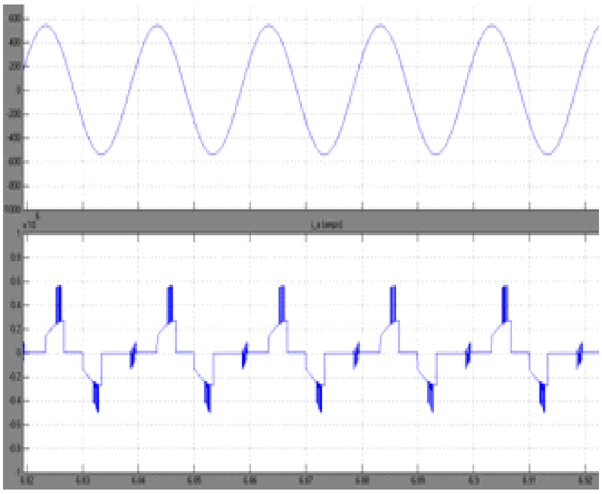

Fig 11 Input Voltage and Current waveforms of the conventional system with no compensator

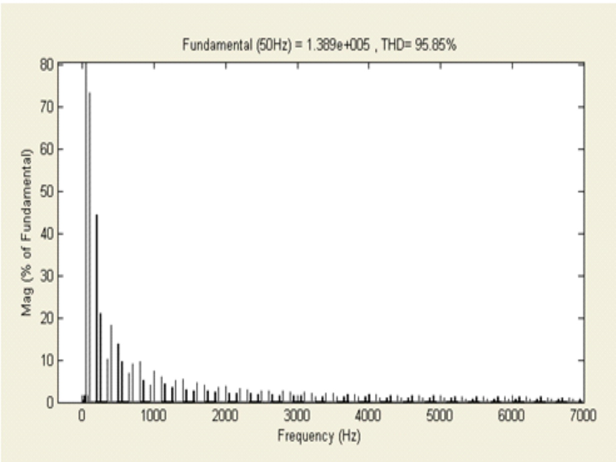

Fig 12 THD of the system without Compensator

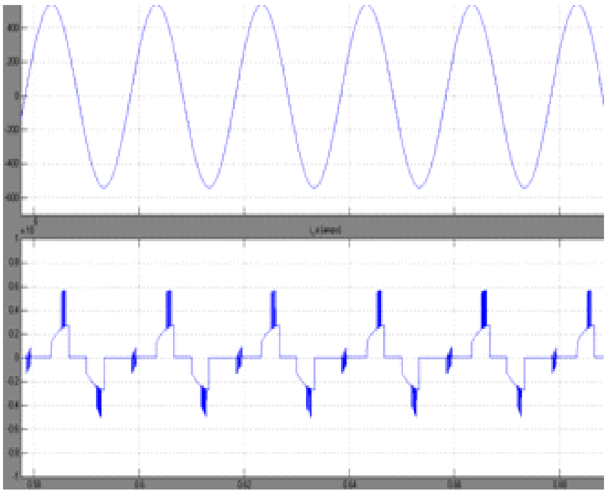

Fig 13 Input Voltage and Current waveforms of the Conventional system with static VAr Compensator

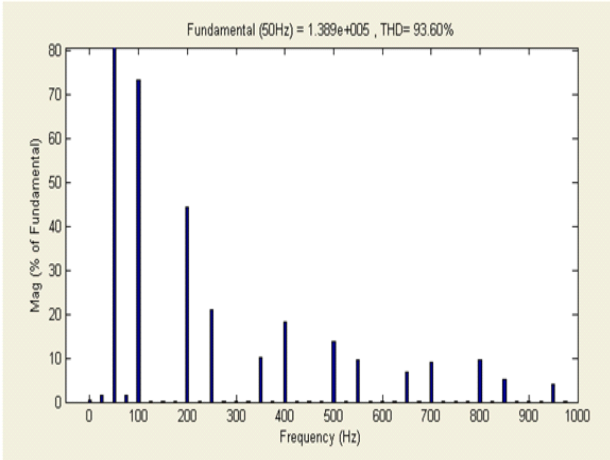

Fig 14 THD of the conventional system with Static VAr Compensator

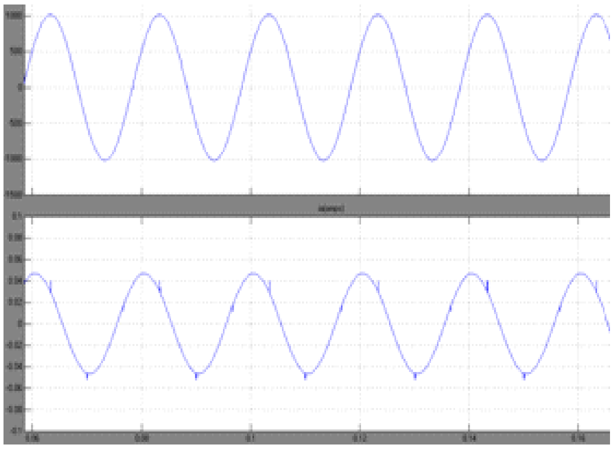

Fig 15 Input Voltage and Input Current waveforms of the system with proposed compensator

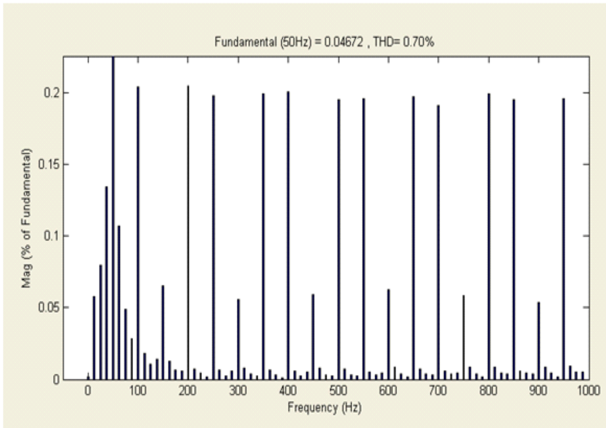

Fig 16 THD of the proposed system with novel compensator.

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VI. CONCLUSIONS

A novel compensating technique for the improvement of power factor in non-linear electrical systems such as power electronic systems is presented in this paper. Vector control is implemented at the supply side of the system. .The reactive component of the supply current is set to zero which is then compared with the actual reactive component of current that is drawn by the system. With the closed loop control the system starts drawing a leading current which implies that the power factor is improved and so the Total Harmonic Distortion is reduced. A conventional system, a conventional power system with static Var Compensator, and a typical power system with the proposed technique are simulated using MATLAB/ SIMULINK and the waveforms of input voltage and input current and the THD for each of them are obtained and compared. It is observed that with the proposed method, the entire system starts drawing a leading current inspite of the non-linear loads connected to the system(the system itself is a non-linear one).The THD value is also found to be reduced to a great extent.

VII. REFERENCES

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